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PATENT TRADEMARK OFFICE

CHAPTER II

**TRANSMITTAL LETTER  
TO THE UNITED STATES ELECTED OFFICE (EO/US)**

**(ENTRY INTO U.S. NATIONAL PHASE UNDER CHAPTER II)**

PCT/DK99/00404

15 JULY 1999

16 JULY 1998

11 SEPTEMBER 1998

INTERNATIONAL APPLICATION NO.

INTERNATIONAL FILING DATE

PRIORITY DATE CLAIMED

A METHOD FOR THE DETERMINATION OF THE CRITICAL CURRENT FOR A CONDUCTOR INCLUDING SUPERCONDUCTING MATERIAL, AND AN APPARATUS FOR PERFORMING THE METHOD

TITLE OF INVENTION

1. MICHAEL BENTZON

APPLICANT(S)

Box PCT

Assistant Commissioner for Patents

Washington D.C. 20231

ATTENTION: EO/US

NOTE: The completion of those filing requirements that can be made at a time later than 30 months from the priority date

**CERTIFICATION UNDER 37 C.F.R. 1.10\***

(Express Mail label number is **mandatory**.)

(Express Mail certification is optional.)

I hereby certify that this correspondence and the documents referred to as attached therein are being deposited with the United States Postal Service on this date JANUARY 8, 2001, in an envelope as "Express Mail Post Office to Addressee," Mailing Label Number EL728210476US, addressed to the: Assistant Commissioner for Patents, Washington, D.C. 20231.

CONNIE YANNOTTI

(type or print name of person mailing paper)

Signature of person mailing paper

**WARNING:** Certificate of mailing (first class) or facsimile transmission procedures of 37 C.F.R. 1.8 cannot be used to obtain a date of mailing or transmission for this correspondence.

**\*WARNING:** Each paper or fee filed by "Express Mail" **must** have the number of the "Express Mail" mailing label placed thereon prior to mailing. 37 C.F.R. 1.10(b).  
"Since the filing of correspondence under § 1.10 without the Express Mail mailing label thereon is an oversight that can be avoided by the exercise of reasonable care, requests for waiver of this requirement will **not** be granted on petition." Notice of Oct. 24, 1996, 60 Fed. Reg. 56,439, at 56,442.

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results from the Commissioner exercising his judgment under the authority granted under 35 USC 371(d). The filing receipt will show the actual date of receipt of the last item completing the entry into the national phase. See 37 C.F.R. §1.491 which states: "An international application enters the national state when the applicant has filed the documents and fees required by 35 USC 371(c) within the periods set forth in § 1.494 and § 1.495."

**WARNING:** Where the items are those which can be submitted to complete the entry of the international application into the national phase are subsequent to 30 months from the priority date the application is still considered to be in the international state and if mailing procedures are utilized to obtain a date the express mail procedure of 37 C.F.R. §1.10 must be used (since international application papers are not covered by an ordinary certificate of mailing - See 37 C.F.R. §1.8).

**NOTE:** Documents and fees must be clearly identified as a submission to enter the national state under 35 USC 371 otherwise the submission will be considered as being made under 35 USC 111. 37 C.F.R. § 1.494(f).

1. Applicant herewith submits to the United States Elected Office (EO/US) the following items under 35 U.S.C. 371:

- a. ☒ This express request to immediately begin national examination procedures (35 U.S.C. 371(f)).
- b. ☒ The U.S. National Fee (35 U.S.C. 371(c)(1)) and other fees (37 C.F.R. § 1.492) as indicated below:

2.Fees

CLAIMS FEE	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
[ ]*	TOTAL CLAIMS	13 - 20 =		x \$ 18.00 =	\$
	INDEPENDENT CLAIMS	2 - 3 =		x \$ 80.00 =	
	MULTIPLE DEPENDENT CLAIM(S) (if applicable) + \$270.00				
BASIC FEE**	<p>[ ] U.S. PTO WAS INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where an International preliminary examination fee as set forth in § 1.482 has been paid on the international application to the U.S. PTO: [ ] and the international preliminary examination report states that the criteria of novelty, inventive step (non-obviousness) and industrial activity, as defined in PCT Article 33(2) to (4) have been satisfied for all the claims presented in the application entering the national stage (37 CFR 1.492(a)(4)) ..... \$100.00 [ ] and the above requirements are not met (37 CFR 1.492(a)(1)) ..... \$690.00</p> <p>[X] U.S. PTO WAS NOT INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where no international preliminary examination fee as set forth in § 1.482 has been paid to the U.S. PTO, and payment of an international search fee as set forth in § 1.445(a)(2) to the U.S. PTO: [ ] has been paid (37 CFR 1.492(a)(2)) ..... \$710.00 [ ] has not been paid (37 CFR 1.492(a)(3)) ..... \$1,000.00 [X] where a search report on the international application has been prepared by the European Patent Office or the Japanese Patent Office (37 CFR 1.492(a)(5)) ..... \$860.00</p>				
	Total of above Calculations				860.00
SMALL ENTITY	Reduction by ½ for filing by small entity, if applicable. Affidavit must be filed. (note 37 CFR 1.9, 1.27, 1.28)				-
	Subtotal				860.00
	Total National Fee				\$ 860.00
	Fee for recording the enclosed assignment document \$40.00 (37 CFR 1.21(h)). (See Item 13 below). See attached "ASSIGNMENT COVER SHEET".				
TOTAL	Total Fees enclosed				\$ 860.00

\*See attached Preliminary Amendment Reducing the Number of Claims.

- i. ☒ A check in the amount of \$860.00 to cover the above fees is enclosed.  
ii. ☐ Please charge Account No. \_\_\_\_\_ in the amount of \$ \_\_\_\_\_.  
A duplicate copy of this sheet is enclosed.

**\*\*WARNING:** "To avoid abandonment of the application the applicant shall furnish to the United States Patent and Trademark Office not later than the expiration of 30 months from the priority date: \* \* \* (2) the basic national fee (see § 1.492(a)). The 30-month time limit may not be extended." 37 C.F.R. § 1.495(b).

**WARNING:** If the translation of the international application and/or the oath or declaration have not been submitted by the applicant within thirty (30) months from the priority date, such requirements may be met within a time period set by the Office. 37 C.F.R. § 1.495(b)(2). The payment of the surcharge set forth in § 1.492(e) is required as a condition for accepting the oath or declaration later than thirty (30) months after the priority date. The payment of the processing fee set forth in § 1.492(f) is required for acceptance of an English translation later than thirty (30) months after the priority date. Failure to comply with these requirements will result in abandonment of the application. The provisions of § 1.136 apply to the period which is set. Notice of Jan. 3, 1993, 1147 O.G. 29 to 40.

3. ☒ A copy of the International application as filed (35 U.S.C. 371(c)(2)):

**NOTE:** Section 1.495 (b) was amended to require that the basic national fee and a copy of the international application must be filed with the Office by 30 months from the priority date to avoid abandonment "The International Bureau normally provides the copy of the international application to the Office in accordance with PCT Article 20. At the same time, the International Bureau notifies applicant of the communication to the Office. In accordance with PCT Rule 47.1, that notice shall be accepted by all designated offices as conclusive evidence that the communication has duly taken place. Thus, if the applicant desires to enter the national stage, the applicant normally need only check to be sure the notice from the International Bureau has been received and then pay the basic national fee by 30 months from the priority date." Notice of Jan. 7, 1993, 1147 O.G. 29 to 40, at 35-36. See item 14c below.

- a. ☐ is transmitted herewith.  
b. ☐ is not required, as the application was filed with the United States Receiving Office.  
c. ☒ has been transmitted  
i. ☒ by the International Bureau.  
Date of mailing of the application (from form PCT/IB/308):  
27 JANUARY 2000.  
ii. ☐ by applicant on \_\_\_\_\_.  
Date

4. ☒ A translation of the International application into the English language (35 U.S.C. 371(c)(2)):  
a. ☒ is transmitted herewith.  
b. ☐ is not required as the application was filed in English.  
c. ☐ was previously transmitted by applicant on \_\_\_\_\_.  
Date  
d. ☐ will follow.

5. ☒ Amendments to the claims of the International application under PCT Article 19 (35 U.S.C. 371(c)(3)):

*NOTE: The Notice of January 7, 1993 points out that 37 C.F.R. § 1.495(a) was amended to clarify the existing and continuing practice that PCT Article 19 amendments must be submitted by 30 months from the priority date and this deadline may not be extended. The Notice further advises that: "The failure to do so will not result in loss of the subject matter of the PCT Article 19 amendments. Applicant may submit that subject matter in a preliminary amendment filed under section 1.121. In many cases, filing an amendment under section 1.121 is preferable since grammatical or idiomatic errors may be corrected." 1147 O.G. 29-40, at 36.*

- a. ☐ are transmitted herewith.
- b. ☐ have been transmitted
  - i. ☐ by the International Bureau.  
Date of mailing of the amendment (from form PCT/IB/308): \_\_\_\_\_.
  - ii. ☐ by applicant on \_\_\_\_\_.  
Date
- c. ☒ have not been transmitted as
  - i. ☒ applicant chose not to make amendments under PCT Article 19.  
Date of mailing of Search Report (from form PCT/ISA/210):  
02 NOVEMBER 1999.
  - ii. ☐ the time limit for the submission of amendments has not yet expired.  
The amendments or a statement that amendments have not been made will be transmitted before the expiration of the time limit under PCT Rule 46.1.

6. ☒ A translation of the amendments to the claims under PCT Article 19 (38 U.S.C. 371(c)(3)):

- a. ☐ is transmitted herewith.
- b. ☐ is not required as the amendments were made in the English language.
- c. ☒ has not been transmitted for reasons indicated at point 5(c) above.

7. ☒ A copy of the international examination report (PCT/IPEA/409)

- ☒ is transmitted herewith.
- ☐ is not required as the application was filed with the United States Receiving Office.

8. ☐ Annex(es) to the international preliminary examination report

- a. ☐ is/are transmitted herewith.
- b. ☐ is/are not required as the application was filed with the United States Receiving Office.

9. ☐ A translation of the annexes to the international preliminary examination report

- a. ☐ is transmitted herewith.
- b. ☐ is not required as the annexes are in the English language.

10. ☒ An oath or declaration of the inventor (35 U.S.C. 371(c)(4)) complying with 35 U.S.C. 115
- a. ☐ was previously submitted by applicant on \_\_\_\_\_.  
Date
- b. ☐ is submitted herewith, and such oath or declaration
- i. ☐ is attached to the application.
- ii. ☐ identifies the application and any amendments under PCT Article 19 that were transmitted as stated in points 3(b) or 3(c) and 5(b); and states that they were reviewed by the inventor as required by 37 C.F.R. 1.70.
- c. ☒ will follow.

Other document(s) or information included:

11. ☒ An International Search Report (PCT/ISA/210) or Declaration under PCT Article 17(2)(a):
- a. ☐ is transmitted herewith.
- b. ☒ has been transmitted by the International Bureau.  
Date of mailing (from form PCT/IB/308): 27 JANUARY 2000.
- c. ☐ is not required, as the application was searched by the United States International Searching Authority.
- d. ☐ will be transmitted promptly upon request.
- e. ☐ has been submitted by applicant on \_\_\_\_\_.  
Date
12. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98:
- a. ☐ is transmitted herewith.  
Also transmitted herewith is/are:
- ☐ Form PTO-1449 (PTO/SB/08A and 08B).
- ☐ Copies of citations listed.
- b. ☐ will be transmitted within THREE MONTHS of the date of submission of requirements under 35 U.S.C. 371(c).
- c. ☐ was previously submitted by applicant on \_\_\_\_\_.  
Date
13. ☐ An assignment document is transmitted herewith for recording.

A separate ☐ "COVER SHEET FOR ASSIGNMENT (DOCUMENT) ACCOMPANYING NEW PATENT APPLICATION" or ☐ FORM PTO 1595 is also attached.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

14. ☒ Additional documents:
- a. ☒ Copy of request (PCT/RO/101)
  - b. ☒ International Publication No. WO 00/04397
    - i. ☒ Specification, claims and drawing
    - ii. ☐ Front page only
  - c. ☒ Preliminary amendment (37 C.F.R. § 1.121)
  - d. ☒ Other

4 PAGES OF FORMAL DRAWINGS; FORM PCT/IB/332;  
FORM PCT/IB/304; FORM PCT/IB/308

15. ☒ The above checked items are being transmitted
- a. ☒ before 30 months from any claimed priority date.
  - b. ☐ after 30 months.
16. ☐ Certain requirements under 35 U.S.C. 371 were previously submitted by the applicant on \_\_\_\_\_, namely:
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

#### AUTHORIZATION TO CHARGE ADDITIONAL FEES

**WARNING:** *Accurately count claims, especially multiple dependent claims, to avoid unexpected high charges if extra claims are authorized.*

**NOTE:** *"A written request may be submitted in an application that is an authorization to treat any concurrent or future reply, requiring a petition for an extension of time under this paragraph for its timely submission, as incorporating a petition for extension of time for the appropriate length of time. An authorization to charge all required fees, fees under § 1.17, or all required extension of time fees will be treated as a constructive petition for an extension of time in any concurrent or future reply requiring a petition for an extension of time under this paragraph for its timely submission. Submission of the fee set forth in § 1.17(a) will also be treated as a constructive petition for an extension of time in any concurrent reply requiring a petition for an extension of time under this paragraph for its timely submission." 37 C.F.R. § 1.136(a)(3).*

**NOTE:** *"Amounts of twenty-five dollars or less will not be returned unless specifically requested within a reasonable time, nor will the payer be notified of such amounts; amounts over twenty-five dollars may be returned by check or, if requested, by credit to a deposit account." 37 C.F.R. § 1.26(a).*

☒ The Commissioner is hereby authorized to charge the following additional fees that may be required by this paper and during the entire pendency of this application to Account No. 12-0425.

☒ 37 C.F.R. 1.492(a)(1), (2), (3), and (4) (filing fees)

**WARNING:** *Because failure to pay the national fee within 30 months without extension (37 C.F.R. § 1.495(b)(2)) results in abandonment of the application, it would be best to always check the above box.*

☐ 37 C.F.R. 1.492(b), (c) and (d) (presentation of extra claims)

**NOTE:** *Because additional fees for excess or multiple dependent claims not paid on filing or on later presentation must*

*only be paid or these claims cancelled by amendment prior to the expiration of the time period set for response by the PTO in any notice of fee deficiency (37 C.F.R. § 1.492(d)), it might be best not to authorize the PTO to charge additional claim fees, except possible when dealing with amendments after final action.*

- ☒ 37 C.F.R. 1.17 (application processing fees)  
☒ 37 C.F.R. 1.17(a)(1)-(5)(extension fees pursuant to § 1.136(a).  
☒ 37 C.F.R. 1.18 (issue fee at or before mailing of Notice of Allowance, pursuant to 37 C.F.R. 1.311(b))

*NOTE: Where an authorization to charge the issue fee to a deposit account has been filed before the mailing of a Notice of Allowance, the issue fee will be automatically charged to the deposit account at the time of mailing the notice of allowance. 37 C.F.R. § 1.311(b).*

*NOTE: 37 C.F.R. 1.28(b) requires "Notification of any change in loss of entitlement to small entity status must be filed in the application . . . prior to paying, or at the time of paying . . . issue fee." From the wording of 37 C.F.R. § 1.28(b): (a) notification of change of status must be made even if the fee is paid as "other than a small entity" and (b) no notification is required if the change is to another small entity.*

- ☐ 37 C.F.R. § 1.492(e) and (f) (surcharge fees for filing the declaration and/or filing an English translation of an International Application later than 30 months after the priority date).

  
SIGNATURE OF PRACTITIONER

WILLIAM R. EVANS

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A method for the determination of the critical current  
for a conductor including superconducting material, and  
an apparatus for performing the method

5 The invention relates to the determination of the critical current for a conductor including superconducting material, and to an apparatus for performing the method.

10 Conductors comprising superconducting material have different uses, e.g. in connection with magnets, transformers, and as conductors for electrical power distribution. Superconducting material is advantageously used in conductors as the superconducting material can be  
15 brought into a superconducting state enabling electrical energy to be transmitted with little energy loss. Reduced electrical power loss is also advantageous as it enables construction of e.g. transformers, magnets, and conductors with smaller dimensions compared to the use of  
20 conventional conductors.

Conductors comprising superconducting material can be constructed as a single core conductor, but is often constructed as a number of filaments arranged to form a  
25 multi-core conductor.

When a superconductor is brought into the superconduction state, e.g. by cooling, electrical power can be transmitted with little loss, as long as the current is  
30 lower than the so-called critical current. The critical current, i.e. that current which the superconductor material is able to support without going into a normally conductive state, is a characteristic value of the given superconductor. It is of great importance to determine  
35 the critical current for a conductor comprising

superconducting material, as the value of the critical current is needed when dimensioning e.g. a transformer including superconductors.

- 5 As the value of the critical current may vary along the conductor, it is of interest to determine the critical current along the superconductor in order to characterize the superconductor. It is of interest to perform the characterization of the conductor as a contact-less  
10 measurement as it enables a continuous determination of the critical current for a conductor over the entire length of the conductor. In addition, the contact-less measurement has the advantage of saving the conductor and the measurement means from wear due to mechanical  
15 contact.

- A method and an apparatus for testing a conductor which consists at least partially of superconductive material is disclosed in US patent 3,976,934. The patent teaches  
20 that the testing of a conductor with superconductive material in the superconducting state can be performed by moving the conductor through an external magnetic field which induces shielding currents in the superconductor material and by measuring the magnetic field generated by  
25 these shielding currents. The critical current is determined using the measured shielding field.

- The object of the invention is to provide a method for the determination of the critical current for a conductor  
30 including superconducting material, which method gives a better and more reliable determination than methods according to the prior art.

- This object is achieved by performing the method as  
35 stated in the characterizing portion of claim 1.

According to the invention, the determination of the critical current for a conductor including superconducting material is performed using a method, wherein said conductor is brought into a superconducting state, and wherein a varying external magnetic field is generated, through which said conductor is conveyed, and wherein a first measurement means is used to carry out a first contact-free measurement of the resulting magnetic field that occurs as a consequence of the influence of the conductor by said external magnetic field. The part of the resulting magnetic field out of phase with the external magnetic field is determined, and the critical current of the conductor is determined on the basis thereof.

The method according to the invention is advantageous as it uses a so-called coupling of the filaments in a conductor having a multi-filament structure to obtain a larger signal to noise ratio for the measured signal due to the fact that the measurement is performed on all the filaments in the conductor. The resulting magnetic field is larger when the filaments are coupled, as each filament hereby contributes constructively to the generation of the resulting magnetic field.

The method according to the invention is advantageous over prior art methods in which the resulting magnetic field, which reflects the value of the critical value, is relatively small due to field suppression. Due to field suppression, that the superconducting characteristics of a superconductor are reduced when exposed to an external magnetic field. Field suppression results in a relatively small magnetic field which reflects the critical current which provides a relatively small signal to noise ratio in the measured signal.

Using a method according to the prior art, it is difficult to obtain an optimum magnetic field in practice as both a too small and a too large external magnetic field result in a magnetic field which is lower than the optimum magnetic field. An optimum external field, when using a method according to the prior art, is a field that is large enough to induce shielding currents in the entire cross-section of the superconductor material to reach the critical current density. As the value of an optimum external value typically varies along the conductor, the measured magnetic field will therefore reflect this unwanted effect. These difficulties are avoided when using a method according to the invention as that part of the resulting magnetic field which is out of phase with the external magnetic field is used to determine the critical current.

In a preferred embodiment, a second measurement is carried out on the resulting magnetic field from another side in relation to the conductor by using a second measurement means. This second measurement is performed in addition to said first measurement of the resulting magnetic field from a first side in relation to the conductor. On the basis of these measurements, a more reliable result can be obtained. It also permits a supervision of the measurement. For example, it is possible to determine the distance between the conductor and the measurement means, and hereby to supervise the conveyance of the conductor, and it is possible to observe differences between the measurements of the different measurement means, which can e.g. be caused by ice on the measurement means.

In a preferred embodiment, compensation is made for measurement variations that occur as a consequence of

variations in distance between conductor and measurement means. This compensation is made on the basis of said first measurement, or any value derived therefrom, and on the basis of said second measurement, or any value derived therefrom.

It is particularly advantageous to perform said compensation by means of the formula  $U = ((A+B) - k(A-B)^2) / 2$ , wherein a corrected field value  $U$  is determined on the basis of the value  $A$  that is the field value from said first measurement or a value derived therefrom, and on the basis of the value  $B$  that is the field value of said second measurement or a value derived therefrom.

The invention also relates to an apparatus for the determination of the critical current for a conductor including a superconducting material adapted to perform the method according to the invention.

The apparatus comprises a conveyor arranged to convey the conductor through the apparatus, a cryostat arranged to cool the conductor to make it assume a superconducting state, a field generation device arranged to generate a varying magnetic field through which the conductor is conveyed, and a first measurement means arranged to carry out a measurement of the resulting magnetic field that occurs as a consequence of the influence of said magnetic field on said conductor. The apparatus further comprises means arranged to determine, on the basis of the measured magnetic field, that part which is out of phase with the resulting magnetic field, and on the basis of this to determine the critical current of the conductor.

In a preferred embodiment of the invention the field generating device comprises Helmholtz coils.

In a preferred embodiment, said first measurement means in the apparatus is arranged to carry out a measurement of the resulting magnetic field from a first side in relation to the conductor, and the apparatus further comprises a second measurement means arranged to carry out a measurement of the resulting magnetic field from another side in relation to the conductor. This is advantageous as the apparatus can be used to perform a more reliable measurement, and to supervise the measurement. Hereby it is possible to determine the distance between the conductor and the measurement means, and to supervise the conveyance of the conductor. By observing the measurements from the different measurement means, it is also possible to determine the differences, which e.g. can be caused by ice on the measurement means.

The apparatus advantageously comprises compensating means arranged to compensate, on the basis of measurements from said first and said second measurement means or values derived therefrom, for measurement variations due to the distance between conductor and measurement means.

Said compensating means is advantageously arranged to carry out said compensation by using the formula  $U = ((A+B) - k(A-B)^2) / 2$ , wherein a corrected field value  $U$  is determined on the basis of said measured field value  $A$  from said first measurement means or any value derived therefrom, and on the basis of the measured field value  $B$  from said second measurement means or any value derived therefrom.

In a preferred embodiment, said cryostat comprises a mechanical control device for controlling the conveyance of the conductor through the cryostat, and said cryostat

is arranged to contain a coolant for cooling the conductor.

5 In a preferred embodiment, the apparatus comprises two separate guides between which the conductor is freely suspended, and said field generating device and measurement device are arranged between the two guides. This is advantageous as the cryostat does not include any movable parts. It is further advantageous as the cryostat  
10 does not include components which could influence the measurements.

Said control device advantageously comprises two slide guides, which is advantageous due to the simple and  
15 hereby sturdy construction.

In a preferred embodiment of the apparatus said guides are made of high density polyethylene. This is advantageous as this material can withstand the influence from  
20 the environment.

The invention will be explained more fully by the following description with reference to the drawing, in which  
25

fig. 1 is a side view of an apparatus according to the present invention,

30 fig. 2 shows a section of the apparatus according to the invention from a second side,

fig. 3 illustrates the coupling of filaments in a conductor including superconducting material, and

35 fig. 4 illustrates the relationship between the shielding field and the external magnetic field, and the

relationship between the remanent field and the external magnetic field.

Fig. 1 shows a preferred embodiment of an apparatus according to the invention. The cryostat containing the cooling medium 14 consists of a central vessel 9 and two tubes 7. A conductor 1 including superconducting material is conveyed from a coil 10 into the cryostat 7,9 through a field generating device 2, out of the cryostat and recoiled 11. The apparatus also comprises a mechanical control device which is designed to assure that the conductor movement in vertical and horizontal directions is restricted and that the conductor is not exposed to bending radius smaller than a given value, e.g. 200 mm. The field generating device 2, which is also called the magnet 2 hereinafter, may be constructed as a pair of Helmholtz coils. In the magnet 2 the field,  $B$ , is normal to the conductor surface and the field strength is advantageously high enough to obtain twice the field of full penetration for the actual superconductor. A first measurement means 5 and a second measurement means 6 are placed above and below the tape respectively. The measurement means 5,6, which are also called magnetic sensors 5,6 hereinafter, may e.g. be Hall probes, inductance coils, or superconducting circuits (squids).

The mechanical control device comprises two slide guides 3,4, which is advantageous due to the simple and hereby sturdy construction. The conductor is freely suspended between the two slide guides which are separated. The field generating device and the measurement device are arranged between the two guides. This is advantageous as the cryostat does not include any movable parts. It is further advantageous as the cryostat does not include components which could influence the performed measurements. The guides are made of high density



polyethylene, but can be made of other material if desired.

When the conductor 1 is conveyed through the apparatus,  
5 by using a conveyor (not shown), the conductor is conveyed through the cooling medium 14 and is hereby brought into a superconducting state. The magnet 2 is adapted to generate a varying external magnetic field through which said conductor is conveyed. Hereby a  
10 magnetic field is generated. A first contact-free measurement of the resulting magnetic field that occurs as a consequence of the influence of said external magnetic field on the conductor is carried out using the first measurement means 5. The resulting magnetic field  
15 is also measured from another side in relation to the conductor using the second measurement means 6. It is advantageous to perform both the first and the second measurement, as they result in a more reliable measurement and make it possible to supervise the  
20 measurement, e.g. to determine the distance between the conductor and the measurement means, and hereby to supervise the conveyance of the conductor. It is also advantageous as it permits observation of differences between the measurements of the different measurement  
25 means 5,6, which can e.g. be caused by ice on the measurement means 5,6, or be caused by defects.

The resulting magnetic field is a sum of the external field and the field induced by the superconductor, i.e.  
30 the so-called self-field. The self-field contains information about the superconducting properties of the tape. These properties are the critical current, the critical current distribution and density, distribution of induced superconducting and non-superconducting  
35 currents, coupling of filaments, filament geometry, induced AC losses, field suppression, etc. All of these

properties will influence the amplitude and time dependence of the self-field. It is noted that the frequency of the varying external magnetic field is given a certain high value in order to ensure coupling of all  
5 the filaments in the conductor 1.

It is determined on the basis of the measurement which part of the resulting magnetic field is out of phase with the external magnetic field. The critical current is  
10 determined on the basis thereof. It is noted that the part of the measured magnetic field which is in phase and out of phase with the external field will be close to the shielding field and the remanent field respectively and are taken as the most important parameters describing the  
15 superconducting properties of the conductor 1.

On basis of the first measurement, or any value derived therefrom, and on the basis of said second measurement, or any value derived therefrom, a compensation is made  
20 for measurement variations that occur as a consequence of variations in distance between conductor 1 and measurement means 5,6. The compensation is e.g. performed by means of the formula  $U = ((A+B) - k(A-B)^2) / 2$ , wherein a corrected field value U is determined on the basis of the  
25 value A that is the field value from said first measurement or a value derived therefrom, and on the basis of the value B that is the field value of said second measurement or a value derived therefrom. It is noted, that k is a constant having a given value, e.g.  
30 0.42.

The method according to the invention is advantageous as the coupling of the filaments in a conductor having a multi-filament structure provides a larger signal to  
35 noise ratio for the measured signal due to the fact that

the measurement is performed on all the filaments in the conductor simultaneously. The resulting magnetic field is larger when the filaments are coupled, which will be described in the following.

5

Fig. 2 shows a section of the apparatus of fig. 1 from a second side. The conveyer means 3 are designed to keep the tape steady in horizontal as well as vertical directions.

10

The conductor 1, which comprises superconducting material, is formed as a tape and includes a number of filaments 8 arranged to form a multi-core conductor. The conductor 1 is also called the tape 1 hereinafter, even though the conductor can also be formed in other ways.

15

Each filament 8 comprises superconducting material and is typically enclosed by another material e.g. silver, in order to give a flexible structure. Different types of superconducting materials are used, and can e.g. comprise Bismuth (Bi), Strontium (Sr), Calcium (Ca) and Copper (Cu) in a given ratio.

20

The filaments 8 in the tape 1 may be coupled due to the time derivative of the external magnetic field. The effect of coupling is that the filaments appear as one superconductor, and this is illustrated by the field lines 20 representing the lines from a single superconductor.

25

30

Fig. 3 illustrates the importance of filament coupling. The figure shows the field above two tapes where the filaments are not coupled (left) and where the filaments are coupled (right). Coupling of filaments increases with the time derivative of the field and with the conductivity of the matrix material. Coupling of the

35

filaments makes the superconducting currents couple together into one loop carrying the critical current. The magnetic field obtained by such a loop is much stronger than the field obtained by several loops. This is  
5 illustrated in the figure by only two filaments. The effect increases with the number of filaments. When the filaments couple, the magnetic field is much bigger and more easy to measure and the relation between the measured field and the critical current is simple to  
10 calculate by using Biot-Savart's law.

Fig. 4 illustrates the relationship between the shielding field and the external magnetic field, and the relationship between the remanent field and the external  
15 magnetic field. The critical current carried by the superconductor depends on the amplitude of the external field. This is due to the field suppression. The remanent field will increase with the external field until saturation occurs around twice the field of full  
20 penetration. Then the remanent field is saturated. The shielding field will start decreasing at higher fields due to the field suppression. The remanent field is advantageously measured when the external field is zero, while the shielding field is at its maximum value. The  
25 remanent field will be a measure of the critical current at zero external field (self field).

It is further noted that the method also may be applied as follows:

30

- 1) The shielding field (the field set up by the SC being in phase with the external field) may be used to determine the critical current at the actual external field amplitude for fields exceeding the field of  
35 full penetration.

- 2) A very reliable determination of the critical current in self field conditions is obtained by comparing the remanent field obtained at high external fields (at least twice the field of full penetration) to the shielding field obtained at low external field (e.g. 10% of the field off full penetration.

In the ratio  $B_{\text{remanent}} (\text{high field}) / B_{\text{shielding}} (\text{low field})$  the influence of geometrical variations (e.g. in the width or thickness of the SC) is cancelled out, and the ratio is therefore a more reliable image of the critical current at self field conditions.

- Although a preferred embodiment of the present invention has been described and shown, the invention is not limited to it, but may also be embodied in other ways within the scope of the subject-matter defined in the appended claims.

P a t e n t   C l a i m s :  
-----

1. A method for the determination of the critical current  
5 for a conductor including superconducting material,  
- wherein said conductor is brought into a  
superconducting state,  
- and wherein a varying external magnetic field is ge-  
nerated through which said conductor is conveyed,  
10 - and wherein a first measurement means is used to carry  
out a first contact-free measurement of the resulting  
magnetic field that occurs as a consequence of the  
influence of said external magnetic field on the  
conductor, c h a r a c t e r i z e d in that the part  
15 of the resulting magnetic field out of phase with the  
external magnetic field is determined, and that the  
critical current of the conductor is determined on the  
basis thereof.
- 20 2. A method according to claim 1, c h a r a c t e r -  
i z e d in that in addition to said first measurement  
of the resulting magnetic field from a first side in  
relation to the conductor, a further, second measurement  
of the resulting magnetic field is carried out from  
25 another side in relation to the conductor using a second  
measurement means.
3. A method according to claim 2, c h a r a c t e r -  
i z e d in that on the basis of said first measurement,  
30 or any value derived therefrom, and on the basis of said  
second measurement, or any value derived therefrom,  
compensation is made for measurement variations that  
occur as a consequence of variations in distance between  
conductor and measurement means.

4. A method according to claim 3, characterized in that said compensation is made by means of the formula  $U = ((A+B) - k(A-B)^2) / 2$ , wherein a corrected field value U is determined on the basis of the value A that is the field value from said first measurement or a value derived therefrom, and on the basis of the value B from that is the field value of said second measurement or a value derived therefrom.

10 5. An apparatus for the determination of the critical current for a conductor including a superconducting material, wherein said apparatus comprises

- a conveyor arranged to convey the conductor through the apparatus
- 15 - a cryostat arranged to cool the conductor and to make it reach a superconducting state,
- a field generation device arranged to generate a varying magnetic field through which the conductor is conveyed, and
- 20 - a first measurement means arranged to carry out a measurement of the resulting magnetic field that occurs as a consequence of the influence of said magnetic field on said conductor,

characterized in that the apparatus further comprises means arranged to determine the part of the of the resulting magnetic field out of phase with the external magnetic field, and on the basis of this to determine the critical current of the conductor.

30 6. An apparatus according to claim 5, characterized in that the field generating device comprises Helmholtz coils.

7. An apparatus according to claim 5 or 6, characterized in that said first

measurement means is arranged to carry out a measurement of the resulting magnetic field from a first side in relation to the conductor, and that the apparatus further comprises a second measurement means arranged to carry  
5 out a measurement of the resulting magnetic field from another side in relation to the conductor.

8. An apparatus according to claim 7,  
c h a r a c t e r i z e d by further comprising  
10 compensating means arranged to compensate, on the basis of measurements from said first and said second measurement means or values derived therefrom, for measurement variations due to the distance between conductor and measurement means.

15  
9. An apparatus according to claim 8,  
c h a r a c t e r i z e d in that said compensating means is arranged to carry out said compensation by using the formula  $U = ((A+B) - k(A-B)^2) / 2$ , wherein a corrected  
20 field value U is determined on the basis of said measured field value A from said first measurement means or any value derived therefrom, and on the basis of the measured field value B from said second measurement means or any value derived therefrom.

25  
10. An apparatus according to one or more of claims 5-9,  
c h a r a c t e r i z e d in that said cryostat comprises a mechanical control device for controlling the conveyance of the conductor through the cryostat, and  
30 that said cryostat is arranged to contain a coolant for cooling the conductor.

11. An apparatus according to claim 10,  
c h a r a c t e r i z e d in that said control device  
35 comprises two separate guides between which the conductor



is freely suspended, and that said field generating device and measurement device are arranged between the two guides.

5 12. An apparatus according to claim 10 or 11, characterized in that said control device comprises two slide guides.

10 13. An apparatus according to claim 12, characterized in that said guides are made of high density polyethylene.

11 14. An apparatus according to claim 12, characterized in that said guides are made of high density polyethylene.

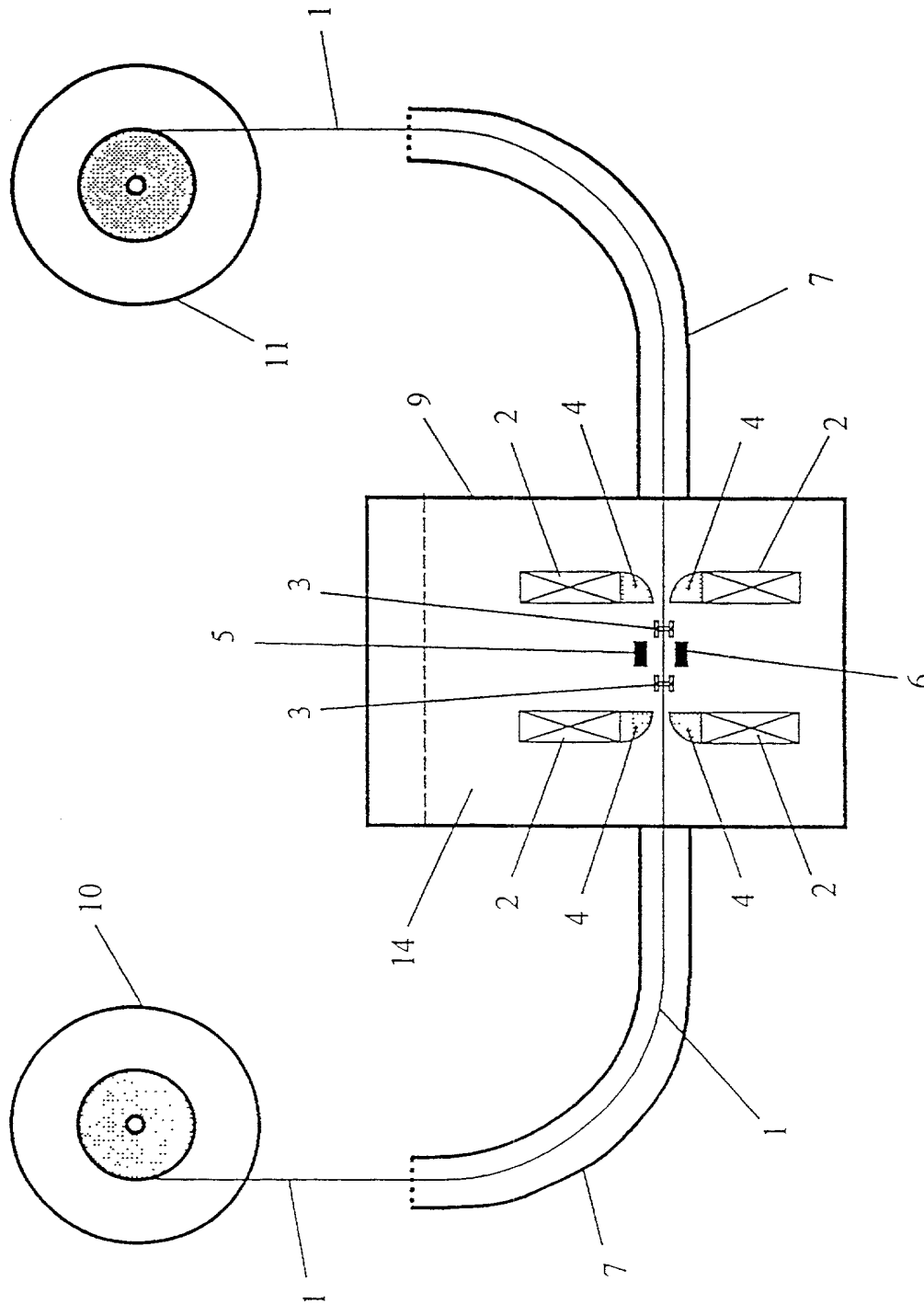


FIG. 1

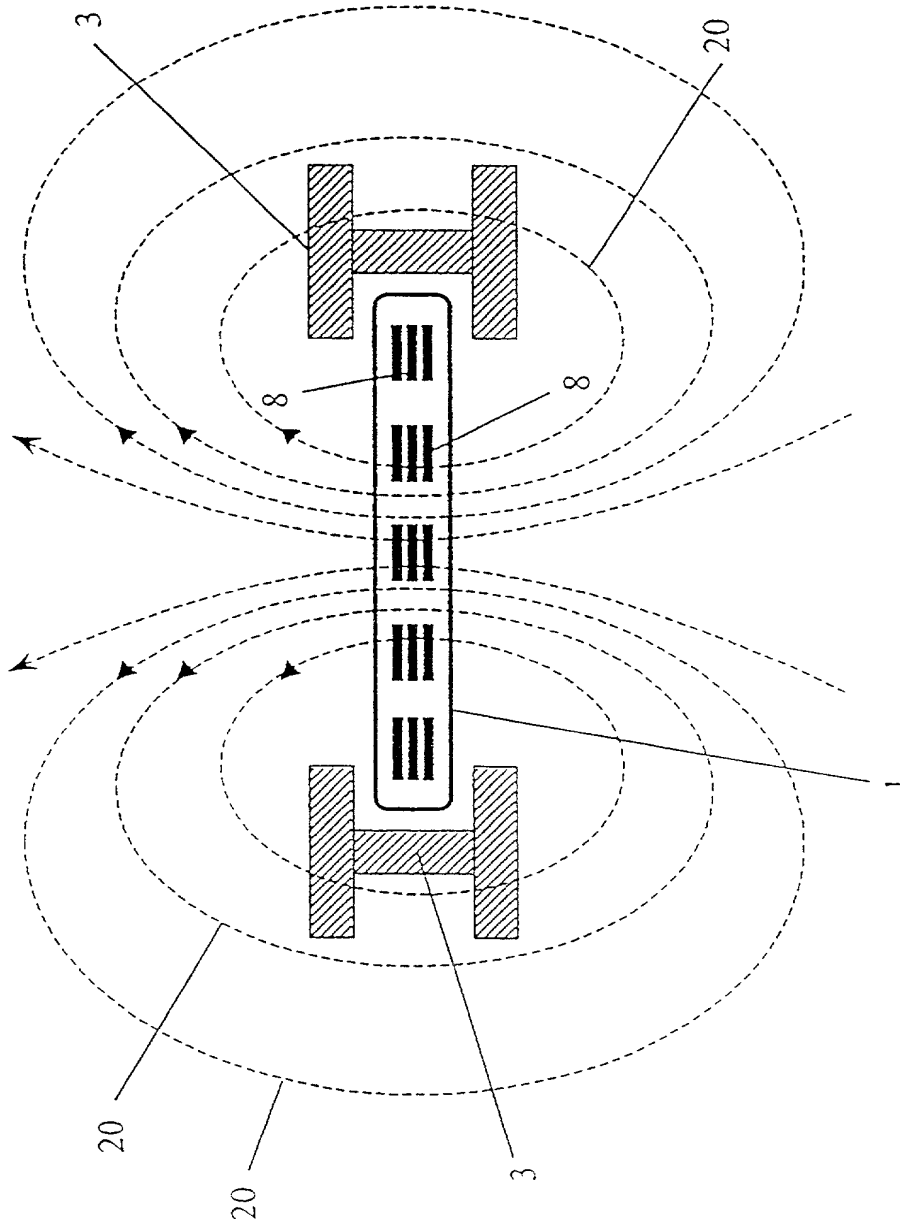


FIG. 2

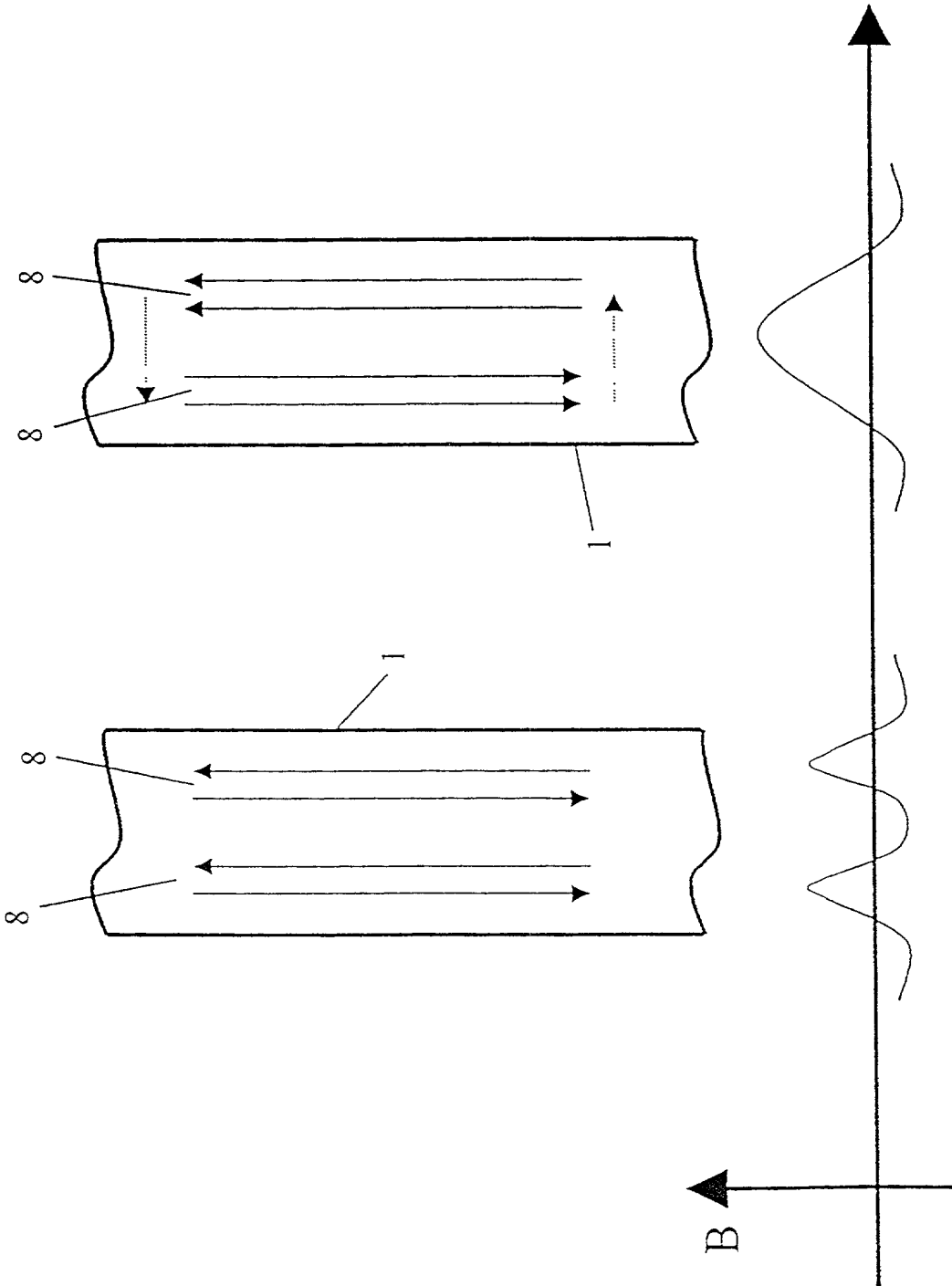


FIG. 3

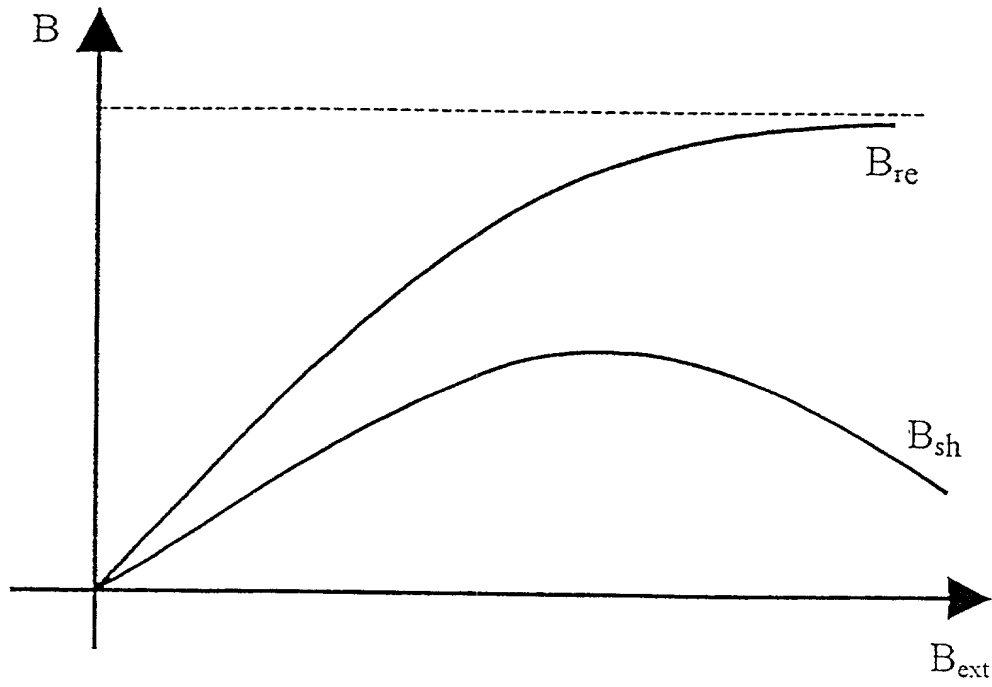


FIG. 4

Attorney's Docket No. U 013198-2**COMBINED DECLARATION AND POWER OF ATTORNEY**(ORIGINAL, DESIGN, NATIONAL STAGE OF PCT, SUPPLEMENTAL, DIVISIONAL,  
CONTINUATION OR CIP)

As a below named inventor, I hereby declare that:

**TYPE OF DECLARATION**

This declaration is of the following type: (check one applicable item below)

- ☐ original  
☐ design  
☐ supplemental

NOTE: If the declaration is for an International Application being filed as a divisional, continuation or continuation-in-part application do not check next item; check appropriate one of last three items.

- ☒ national stage of PCT

NOTE: If one of the following 3 items apply then complete and also attach ADDED PAGES FOR DIVISIONAL, CONTINUATION OR CIP.

- ☐ divisional  
☐ continuation  
☐ continuation-in-part (CIP)

**INVENTORSHIP IDENTIFICATION**

WARNING: If the inventors are each not the inventors of all the claims an explanation of the facts, including the ownership of all the claims at the time the last claimed invention was made, should be submitted.

My residence, post office address and citizenship are as stated below next to my name. I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**TITLE OF INVENTION**

A method for the determination of the critical current for a conductor including superconducting material, and an apparatus for performing the method

**SPECIFICATION IDENTIFICATION**

the specification of which: (complete (a), (b) or (c))

- (a) ☐ is attached hereto.  
 (b) ☐ was filed on \_\_\_\_\_ as ☐ Serial No. 0 / \_\_\_\_\_  
 or ☐ Express Mail No., as Serial No. not yet known \_\_\_\_\_  
 and was amended on \_\_\_\_\_ (if applicable).

NOTE: Amendments filed after the original papers are deposited with the PTO which contain new matter are not accorded a filing date by being referred to in the declaration. Accordingly, the amendments involved are those filed with the application papers or, in the case of a supplemental declaration, are those amendments claiming matter not encompassed in the original statement of invention or claims. See 37 CFR 1.67.

(Declaration and Power of Attorney [1-1]—page 1 of 4)

- (c) ☒ was described and claimed in PCT International Application No. PCT/DK99/00404 filed on July 15, 1999 and as amended under PCT Article 19 on \_\_\_\_\_ (if any).

#### ACKNOWLEDGEMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

- ☐ In compliance with this duty there is attached an information disclosure statement. 37 CFR 1.97.

#### PRIORITY CLAIM

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

(complete (d) or (e))

- (d) ☐ no such applications have been filed.  
(e) ☒ such applications have been filed as follows.

NOTE: Where item (c) is entered above and the International Application which designated the U.S. claimed priority check item (e), enter the details below and make the priority claim.

#### EARLIEST FOREIGN APPLICATION(S), IF ANY FILED WITHIN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION

COUNTRY	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 37 USC 119
Denmark	PA 1998 00944	16 July 1998	<input checked="" type="checkbox"/> YES NO <input type="checkbox"/>
Denmark	PA 1998 01148	11 Sept 1998	<input checked="" type="checkbox"/> YES NO <input type="checkbox"/>
			<input type="checkbox"/> YES NO <input type="checkbox"/>
			<input type="checkbox"/> YES NO <input type="checkbox"/>
			<input type="checkbox"/> YES NO <input type="checkbox"/>

#### ALL FOREIGN APPLICATION(S), IF ANY FILED MORE THAN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION

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POWER OF ATTORNEY

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (List name and registration number)

14  
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JOSEPH H. HANDELMAN, 26179  
JOHN RICHARDS, 31053  
JOHN J. CRYSTAL, 26360  
RICHARD J. STREIT, 25765  
ALAN K. ROBERTS, 17777  
S. DELVALLE GOLDSMITH, 14383

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THOMAS F. PETERSON, 24790  
RICHARD P. BERG, 28145  
JULIAN H. COHEN, 20302  
WILLIAM R. EVANS, 25858

☐ Attached as part of this declaration and power of attorney is the authorization of the above-named attorney(s) to accept and follow instructions from my representative(s).

SEND CORRESPONDENCE TO

DIRECT TELEPHONE CALLS TO  
(Name and telephone number)

LADAS & PARRY  
26 WEST 61ST STREET  
NEW YORK, NEW YORK 10023

(212)708-1930

DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE(S)

Full name of sole or first inventor BENTZON, Michael Deleuran

Inventor's signature [Signature]

Date 11-1-2001 Country of Citizenship Denmark

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Post Office Address Same as above

Full name of second joint inventor, if any \_\_\_\_\_

Inventor's signature \_\_\_\_\_

Date \_\_\_\_\_ Country of Citizenship \_\_\_\_\_

Residence \_\_\_\_\_

Post Office Address \_\_\_\_\_



**CHECK PROPER BOX(ES) FOR ANY OF THE FOLLOWING ADDED PAGE(S) WHICH  
FORM A PART OF THIS DECLARATION**

- ☐ Signature for third and subsequent joint inventors. *Number of pages added* \_\_\_\_\_
- ☐ Signature by administrator(trix), executor(trix) or legal representative for deceased or incapacitated inventor. *Number of pages added* \_\_\_\_\_
- ☐ Signature for inventor who refuses to sign or cannot be reached by person authorized under 37 CFR 1.47. *Number of pages added* \_\_\_\_\_

...

- ☐ Added pages to combined declaration and power of attorney for divisional, continuation, or continuation-in-part (CIP) application.
- ☐ Number of pages added \_\_\_\_\_

...

- ☐ Authorization of attorney(s) to accept and follow instructions from representative

...

***If no further pages form a part of this Declaration then end this Declaration with this page and check the following item***

- ☐ **This declaration ends with this page**

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